STUDY ON THE PERFORMANCE OF DIFFERENT SLOPE INCLINATION OF VEGETATED ROOF

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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DEDICATION

Allah, my creator and my master, my greatest teacher and messenger,
Mohammad who taught us the purpose of life.

I dedicate this special gratitude to my loving parents, *Hj. A. Razak Bin Mohammed* and *Hjh. Rashnah Binti Yaacob* whose words of encouragement and push for tenacity ring in my ears. My beloved sisters *Ashra, Elly* and *Julaikha* have never left my side and are very special. To my uncle *Harris Bin Abdullah* who had helped me a lot with my thesis writing. My beloved husband *Ahmad Fitri Bin Ahmad* who has supported me throughout the process and my beloved son *Ahmad Al Fariq Bin Ahmad Fitri* has been a very good boy and has given me the courage through thick and thin during my thesis writing. I will always appreciate for all they have done. Thank you so much.

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ABSTRACT

The vegetated roof is well known for its aesthetic value and is able to save the ecological system. It has the potential to reduce rainwater and air run before it gets to the surface. Rainwater is collected in this system before it is released into the drainage system (drains). The purpose of this study is to diagnose non-vegetative roofing capabilities and vegetation roofs to relieve rainwater flow and to study the abilities of vegetated roofs in hiding rainwater. This study has 4 roofs with 2 vegetated roof and the other 2 roofs is without vegetation. It also has 2 different roof trends (10° and 30°). All the roofs have the same roof size of 600 mm × 600 mm, have a geotextile layer, 80 mm thickness with the same mixture of perlite, vermiculite and peat moss and the plants used for this study are Portulaca Grandiflora. Based on the first findings, vegetated with 30° roof angle collected 4.20 mm while 10° roof angled collected 0.48 mm of rainfall. There is approximately 4 minutes delay for 30° roof before the rainfall being captures from the vegetated roof and 10 minutes delay for 10° roof angle. For light rainfall, the peak of the event recorded was 0.40 mm. Vegetated with 30° roof angled collected 0.05 mm and 10° roof collected 0.045 mm of rainfall which is almost the same value. This shows that 10° and 30° vegetated roof and this shows that vegetated roofs with 30° roof angle did manage to retain certain amount of rainfall but the best roof angle was 10° roof slope because it could retain more rain water compared to 30° roof.

ABSTRAK

Bumbung bervegetasi terkenal dengan nilai estetika dan mampu menyelamatkan sistem ekologi. Ini berpotensi untuk mengurangi air hujan dan udara sebelum sampai ke permukaan. Air hujan dikumpulkan dalam sistem ini sebelum dibebaskan ke dalam sistem saliran (longkang). Tujuan kajian ini adalah untuk mendiagnosis keupayaan bumbung tanpa vegetasi dan bumbung bervegetasi untuk melegakan aliran air hujan dan mengkaji kebolehan atap berumput dalam menyembunyikan air hujan. Kajian ini menggunakan 4 bumbung 2 daripadanya bumbung bervegetasi dan 2 lagi bumbung tanpa vegetasi. Ia juga mempunyai 2 tren bumbung yang berbeza (10° dan 30°). Semua bumbung mempunyai ukuran bumbung yang sama 600 mm × 600 mm, mempunyai lapisan geotekstil, ketebalan 80 mm dengan campuran perlite, vermikulit dan lumut gambut yang sama dan tanaman yang digunakan untuk kajian ini adalah Portulaca Grandiflora. Berdasarkan penemuan pertama, tumbuh-tumbuhan dengan sudut atap 30° dikumpulkan 4.20 mm sementara sudut bumbung 10° mengumpulkan 0.48 mm curah hujan. Terdapat kira-kira 4 minit kelewatan untuk atap 30° sebelum hujan diambil dari bumbung tumbuh-tumbuhan dan 10 minit kelewatan untuk sudut bumbung 10°. Untuk curah hujan ringan, puncak acara yang dicatat adalah 0.40 mm. Sayuran dengan bumbung bersudut 30° dikumpulkan 0.05 mm dan bumbung 10° mengumpulkan 0.045 mm hujan yang nilainya hampir sama. Ini menunjukkan bahawa atap tumbuh-tumbuhan 10° dan 30° dan ini menunjukkan bahawa atap tumbuh-tumbuhan dengan sudut bumbung 30° berjaya mengekalkan jumlah curah hujan tetapi sudut bumbung terbaik adalah cerun bumbung 10° kerana dapat mengekalkan lebih banyak air hujan berbanding 30° bumbung.

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LIST OF SYMBOLS AND ABBREVIATIONS

€	- Euro
%	- Percent
≥	- More than or equal
≤	- Less than or equal
º	- Degree of Roof Slope
ºC	- Degree Celsius
√	- Square Root
()	- Bracket
±	- Plus- minus
UTHM	- Universiti Tun Hussein Onn Malaysia
mm	- Millimeter
cm	- Centimeter
P	- Precipitation
Q	- Flow Runoff
E	- Evaporation
Δs	- Storage in Soil
MSMA	- Manual Saliran Mesra Alam
BMPs	- Best Management Practices
SUDS	- Sustainable Urban Drainage System
UK	- United Kingdom
LID	- Low Impact Development
USA	- United States of America
WSUD	- Water Sensitive Urban Design
NGOs	- Non- Government Organisations
KeTTHA	- Kementerian Tenaga Teknologi Hujau dan Air
ACEM	- Association of Consulting Engineers Malaysia
PAM	- Persatuan Arkitek Malaysia
GBI	- Green Building Index

kg	- Kilogram
m^2	- Square Meter
FLL	- German Landscape Research, Development and Construction Society
SwellGel	- Polyacrylamide Water Absorbent Gel
SAP	- Super Absorbent Polymer
WHC	- Water Holding Capacity
GR	- Green Roof
RECESS	- Research Centre For Soft Soil
C_d	- Coefficient of Discharge
H	- Height Above Weir
g	- Local Acceleration Gravity
Ɵ	- V-notch angle
tan	- Tangent
s	- Second
mL	- Milliliter
FS	- Full Scale

CHAPTER 1

INTRODUCTION

1.1 Background of study

Vegetated roofs in Malaysia can be considered as fairly new to the country although it offers a creative solution in solving environmental problems. Basically, vegetated roof system is an extension of the existing roof. The system includes water-proofing, drainage system, filter cloth, lightweight growing medium, and plants. In Asia, the usage of vegetated roof has emerged in Japan, Singapore, Hong Kong and China. These countries have been developing, practicing and conducting research on vegetated roof. Due to its remarkable performances across the world, currently the implementation of vegetated roof in Malaysia increasing and accepted by the industry. Vegetated roof system can be classified into two types, extensive and intensive. Generally, intensive vegetated roof is more difficult to maintain compared to extensive vegetated roof because of the maintenance cost is much more expensive since it requires thicker substrate depth to allow more varieties of plant selection like trees, shrubs and grass and it also require stronger structure loading support. Extensive vegetated roof is easier to maintain and require less maintenance as the plants selected usually has higher survivability and requires less attention to maintain. These research focus on extensive systems as they would be a good start for Malaysia to adopt vegetated roof systems due to low cost and easy implementation compared to intensive systems (Townshend, 2007). Most of the vegetated roof systems in Malaysia uses conventional materials such as polymers in the filter and drainage layer. There are a lot possible waste and recycle materials that can replace the conventional materials in vegetated roof. In choosing the best materials, considerations need to be taken to

incorporate waste and recycled materials in the design of the extensive vegetated roof so that it is more beneficial from the environmental and economic aspect (Siew, Chin & Sakundarini, 2019). However, there are several successful vegetated roof systems applied in Malaysia buildings such as Putrajaya International Convention Centre, Sime Darby Oasis, KL Sentral @ Platinum and many more (Zahir *et al.*, 2014).

1.2 Problem statement

Malaysia is well known as a tropical climate country. Due to rapid development, it gives poor impact towards the stormwater management. This happened when natural environment has been turned into built environment and this significantly affects the natural landscape. Flash floods usually occur in areas with more impervious areas and causes rapid rise in water level, duration of rainfall as well as the steepness of watershed, stream gradient and large amounts of debris (Buslima *et al.,* 2018). Now, Malaysia is receiving 3500 mm of rainfall yearly and have a large area of tropical rainforest which acts as water catchment area. Malaysia still facing with major stormwater problems such as flash flood, water shortage and water pollution due to rapid urbanization, increasing population, agriculture activities, deforestation and other activities involving of land use. As the years gone by, the problems are getting serious (Zakaria *et al.*, 2004). Conventional method in stormwater management is using concrete drain and this cannot fulfill the expectation in controlling the volume and quality of runoff water and this may cause flash flood in downstream area. In 2012, Department of Irrigation and Drainage (DID) has launched an Urban Stormwater Manual of Malaysia (MSMA). This manual promotes the application of Sustainable Urban Drainage System (SUDS) and vegetated roof is one of the facilities falls under SUDS. Vegetated roof provides numerous benefits such as attenuating stormwater runoff and improve stormwater quality, but it also can create new habitat, filter pollution, decrease noise, improve air quality, reduce microclimate and etc. (Ayub, Ab. Ghani & Zakaria, 2015). For example, study on vegetated roof in reducing quantity of stormwater runoff. They developed two flat type roof models in a small scale which are vegetated (test) and non- vegetated (control). The results show that vegetated roof model retained 17% to 48% of the stormwater (Musa *et al.*, 2011). Vegetated roof seems to be the most effective method in solving these problems as this paper will discuss in further details.

1.3 Objectives of study

This research has carried out three objectives to support the problem statement. Followings are the objectives: -

a) To study the ability of non- vegetated roof and vegetated roof in retaining rainfall water
b) To investigate the performance of different roof slopes inclination towards reducing rainfall runoff.
c) To evaluate the performance of vegetated roof in terms of roof runoff

1.4 Scope of study

This study started in April 2016 and ended in August 2016 (5 months duration). The study is basically focus more on testing the vegetated roof with two different angles (10° and 30°). There are four numbers of small-scale roofs were built, two of which were 10° inclined roofs and the other two were 30° inclined roofs. All four small scale roofs were placed at the Research Centre of Soft Soil at UTHM. The size of the vegetated roof planter box is 600 mm x 600 mm x 150mm with 80mm of soil thickness and vegetation used in this study is *Portulaca Grandiflora* (Japanese Rose). In order to measure the runoff of each roofs, the weir box was installed under each roof to measure runoff. To measure the rainfall, Hobo rain gauge was used.

1.5 Importance of study

Vegetated roofs are part of an urban greening strategy. It provides an effective strategy in solving environmental problems, a creative solution for space scarcity in an urban area as well as increase human quality of life (Garcia, 2017). Vegetated roofs are very relevant in Malaysia since now experiencing rapid urbanization and loss of green areas at most of its major cities. For example, in Kuala Lumpur urban area decreased the green area per capita which was 13 square meters in 2010 to 8.5 square meter in 2014 (Ismail *et al.,* 2018). In Malaysia, there are many buildings having vegetated roofs but there are certain obstacles which is lack of expertise and professionals, high material cost and lack of scientific studies of green roof done locally. Therefore, the importance

of this study is to provide knowledge on vegetated roofs and hoping to help in future reference or study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Malaysian economy has gone through rapid structure change since independence in 1957. The urban growth is vast in accordance with the rapid economic growth and industrialization. The infrastructure has been strained by the urban growth and high needs of improvement of amenities such as water supply, electricity, transportation, environment and drainage. In order to make these changes, large of impervious areas are constructed and the results is changing the hydrological cycle (Zakaria *et al.*, 2004). Therefore, this chapter will review and discuss on the concept of vegetated roof, the benefits of vegetated roof and also provide a better understanding about vegetated roof. At the same time, review on vegetated roofs the importance, the advantages and disadvantages, types of vegetated roofs, the configuration of vegetated roofs, the different slope inclination and its performances based on previous research conducted.

2.2 Hydrological cycle in urban area

Hydrological cycle is a continuous circulation of water through the hydrosphere, atmosphere, lithosphere and biosphere. It is a dynamic and integrated system with multiplicity of processes including precipitation, infiltration, evaporation, interception, condensation, etc. (Sun, Limburg & Hong, 2019). Hydrological is clearly defined as in Figure 2.1 which the source from Easton & Bock (2015).

Over the past few decades, the field of hydrology has better understanding on some impacts of urban development towards natural hydrological processes

(McGrane, 2016). The flow path of surface runoff may change significantly due to the land characteristics. Urbanization has changed the land use in Malaysia from forest, agriculture and green habitats to suburban and urban environments and this eliminates the transpiration process and increased the impervious areas which will not allow infiltration process to the ground (Misni & Amir, 2017; Jamaluddin,2017). These causes significant changes in stormwater flow patterns on lower area water catchment, water runoff and movement during storm events, quality of water, ultimate conditions nearby water catchment areas and soil erosion problems causes from the limitation of vegetation cover which exposes the soil to the impact of rain. These changes has affected the natural water movement (Tucci, 2001; Goonetilleke & Thomas, 2003; Erlandsson, 2014). According to Misni & Amir (2017), there are several ways to mitigate these negatives environmental impacts which related to flash floods problems. Basically, stormwater management is the control of the surface runoff and by applying soft landscape engineering treatment will help to alleviate these effects. Hence, this practice will also help to reduce and limit the negative impacts on the environment while enhancing the hydraulic cycle needs of a development (Debo & Reese, 2003).

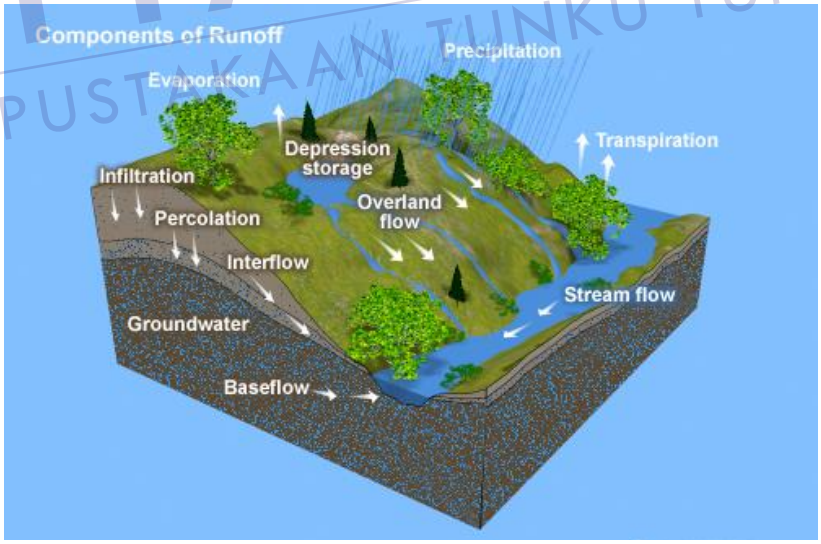

Figure 2.1: The basic hydrological cycle
(Easton & Bock, 2015)

Rapid urbanisation in Malaysia has shown from the progressive movement from agriculture to an industrialised economy which shift the population into urban centers. A total of 26.8 % of the population were urban dwellers back in 1970. By

1980 the population has increased to 35.8 % and 50.7 % in 1991. Recent projection indicates that the urban population in Malaysia by the year 2020 will increased exceeding 65 %. These developments will not stop because it will need to comply with the necessity of the urban dwellers and this will result in paved surfaces. According to Abdullah (2000), a study was conducted in Subang Jaya, Malaysia, the most populated area an increase in impervious area from 0-40% have shortened the time of concentration by about 50% and increased the magnitude of the runoff discharge by about 190%. Rapid and poorly envisaged urbanisation has led to floods (Chan, 2016). The increased in impervious areas leads to incidents of flash floods in Malaysian urban areas as shown in figure 2.2 article from The Star. Studies conducted by Department of Irrigation and Drainage Malaysia shows surface runoff using drainage system from the development area based on conventional approach will increase two times the peak discharged and rapidly discharge to the nearest river system and it also shows the capabilities of rivers to cater the surface runoff is decreasing. Therefore, Storm Water Management manual provided by the government will help the government and private sector in reducing surface runoff from discharge directly into the river and for a long term it will help to minimise the expenditure on flood mitigation.

Figure 2.2: Flooded by heavy rains in town of Segamat, Johor caused the Segamat river and other rivers to overflow their banks
(Chan, 2016)

In order to minimise the disturbance occurs in the hydrological regimes, planners need to have basic knowledge of hydrological process towards urban storm drainage, understanding of impacts of urbanization and surface runoff and awareness

on methods to mitigate hydrological impacts towards urbanisations. The trick is to ensure that the construction effects are minimal and does not affect the hydrological cycle.

2.3 Stormwater management in Malaysia

Malaysia has gone through rapid changes in urban growth, economic growth and industrialization since independence in 1957. From the vast urban growth, improvement in amenities such as water supply, electricity, transportation, environment and drainage are highly needed. In order to implement these desires, large impervious areas are constructed and this changes the hydrological cycle such as infiltration, pattern of surface, river runoff, imposing high peak flows, large runoff volumes, pollutions and sediment from urban areas (Jamaluddin, 2017).

Traditional stormwater management design just focused on collecting stormwater in piped network and transport it as quick as possible either direct to stream or river, to a large stormwater management facility (basin) or to combined sewer system flowing to a wastewater treatment plant (Jamaluddin, 2017). Malaysia has experienced several cases of major flood since 1920. In 2014 Kelantan and other few east coast was hit by major flash floods. It started with continuously raining from 17th December 2014 and led to flash flood and forced 3390 people in Kuala Krai, Kelantan to move out from their homes. The total rainfall recorded was 1295 mm, this equivalent to the amount of rain usually in a span for 64 days. Figure 2.3 shows the Kelantan stadium area was flooded with flood water. As a result, water level for three major rivers rose drastically above the water level and it considered as dangerous (Baharuddin *et al.,* 2015).

According to Misni & Amir (2017), floods can be classified into two categories such as flash floods and monsoon floods. Flash floods take only some hours to return to the normal water level but for monsoon floods can last for a month. Flash floods are the stormwater runoff component caused by human activities and land development that change the natural water balance. Stormwater management method was to control at source since it involves in controlling the surface runoff by reducing stormwater runoff rates, runoff volumes and also stormwater pollutions (Ghani *et al.,* 2004). Schueler (2000) mentioned that stormwater management is needed to mitigate the possible impacts of impervious surfaces. It also concerned in the application of site

design principles, construction techniques and source controls to reduce the impacts of altered hydrology.

Figure 2.3: Kelantan football stadium was filled with floodwaters (Baharuddin *et al.*, 2015)

Urban Stormwater Management Manual for Malaysia or better known as *Manual Saliran Mesra Alam (MSMA)* is prepared by the DID to replace the old manual called Planning and Design Procedure No.1: Urban Drainage Design Standard for Peninsular Malaysia, 1975. This manual is to be used to regulate development works and assist relevant parties towards achieving sustainable development (Ghani, Shafiei & Daud, 2002). The concept of stormwater management control is relatively new in Malaysia. The new manuals draw on various approach of Best Management Practices now is being practices worldwide to control the quantity and quality runoff through detention/retention storage, infiltration facilities, engineered water way which are capable to retard the flow (Jamaluddin, 2017). Studies carried out by Misni & Amir (2017) on minimizing stormwater runoff at Section 13, Shah Alam, Malaysia. The focus was on the benefits of landscape approach via the use of low-impact development (LID) strategies combined with soft landscape engineering in solving flash flood issues. The situation was regardless of several solutions, the water peak runoff has drastically increased since 2003 as a result from 34.8 % development. Results shows the estimation of water peak runoff can be reduced by 7.9 %, which equal to 81.77 m^3/h. Therefore, it hopes that it will help in solving more problems related to flash floods. Since Malaysia is going towards green construction which are

more widely considering the stormwater management design, any development in Malaysia is compulsory to follow MSMA design concepts. The implementation of urban stormwater management in Malaysia hopefully can enhance environmental quality and life (Jamaluddin, 2017).

2.4 Vegetated roof

Vegetated roofs have captured people's imagination all over the world. In North of America, Europe, China, Southeast Asia, Australia and New Zealand and vegetated roofs have surged in popularity because they just seem right by the way they look and of the benefits they bring to the building's users and owners and to the people who see the building and to the wider surroundings that the building sits within (Dunnett *et al.,* 2011). Vegetated roof is also part of an urban greening strategy for climate change adaptation. It provides an effective strategy in addressing environmental problems, a creative solution for space scarcity in an urban area as well as increase human quality of life (Garcia, 2017). Malaysia is experiencing rapid urbanization and loss of green areas at most cities and the application of vegetated roof is very relevant. In Kuala Lumpur itself decreases the vegetated area per capita which was 13 square meters in 2010 to 8.5 square meter in 2014. Vegetated roof has existed in Malaysia on our built environment and are widely known as roof top garden (Hussin & Raid, 2013). Vegetated roof basically is a vegetated area created by adding layers of growing medium/ soil and plants on top of a traditional roofing system. It is a technology of integrating plants with built environment. Vegetated roof or planted roof can be defined as roof that consist of vegetation and growing medium and also refer to roof garden in other places (Dunnet & Kingsbury, 2004). The concept of eco-roof nowadays has increasingly popular as it brings many benefits towards the environment and promoting sustainable lifestyle. In Malaysia there are no design guideline but the application of vegetated roof system is getting increase (Saharuddin, Khalil & Salleh, 2017).

Generally, vegetated roofs can be divided into two types extensive of intensive vegetated roofs (Rahman *et al.,* 2015; Rahman, Ahmad & Rosley, 2013; Hui, 2010; Silva, Flores-Colen & Coelho, 2015; Jim, 2017). Recently, Roseli *et al.,* (2019) mentioned there are four types of vegetated roof which are extensive, semi-intensive, intensive and elevated landscape. The primary differences between the four types is

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